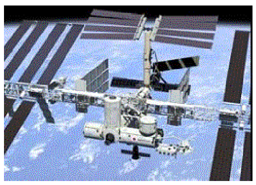
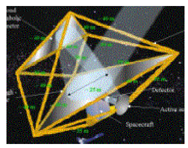
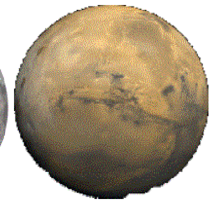
EVA
PROJECT
OFFICE

The Future of EVA Technologies

JSC/HQ/R. Fullerton
rfullert@hq.nasa.gov
202-358-1453

November 6, 2001

Optimizing the Human/Robotic Partnership

- Humans and robots have collaborated in every NASA mission
  - **Difference between missions is the physical interfaces and proximity of humans**
- Hubble Space Telescope and Apollo demonstrated significant increase in rate of science return through involvement of humans at local science site
- Humans and robots represent different tools for accomplishing different jobs
  - **Humans have capabilities not yet attained by robotics**
  - **Robots more efficient for repetitive tasks and expendable for high risk tasks**
- Understanding benefits and risks of human and robotic capabilities is complex and evolving
- Must optimize integration of humans and machines to maximize overall capabilities for effective scientific discovery



Task Implementation Options (Planetary Exploration Example)

Robot Method	Human Role	Site Access	Data Scope	Rel Cost	Hdw Repair	Safety Risk
Remote teleoperation	Earth based control	Lowest	Lowest	Low	None	None
Fully automated	Earth based monitoring	Low	Low	Low-Med	None	None
Local teleoperation	Orbital habitat	Low	Low-Med	Med	None	Low
Local teleoperation	Lander habitat-No EVA	Low	Low-Med	Med-Hi	None	High
Variable autonomy	Lander habitat-No EVA	Low	Med	Med-Hi	None	High
Variable autonomy (pressurized garage)	Lander habitat-No EVA	Low	Med	Med-Hi	Partial	High
Variable autonomy (dockable to habitat)	Canned mobility (No EVA Capability)	Low-Med	Med	High	Partial	Highest
Precursors only	Suited humans on foot	Med-Hi	High	Med-Hi	Full	Med
Variable autonomy (total crew access)	Suited transportable humans (w/Rovers)	Highest	Highest	Highest	Full	Med-Hi

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Current State of EVA

Existing NASA EVA architecture is over 24 years old (1977) and has evolved from Apollo, Skylab and Shuttle technology and operations.

All current EVA systems are only compatible with low earth orbit zero-G activities and require costly regular ground based maintenance, resupply and monitoring.

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Summary of Existing Architecture Challenges

environment	•Suit mass, mobility, visibility and comfort are not compatible with partial gravity planetary environments. Suited body control and work area in zero gravity is hampered. •Suit protection from dust intrusion is inadequate. •Available thermal insulation materials either only work in vacuum conditions or are thick and impede suit mobility and glove dexterity. Even with active heating, touch temperatures are limited to short durations and narrow ranges (-120 to +150F). •Radiation definition, monitoring and protection are inadequate beyond earth's ionosphere. •Sensitive environments and science devices are contaminated from suit by-products
productivity	•EVA information processing is limited to simple radio voice, suit/medical telemetry and is based on old technology that is not inflight reprogrammable. No hands free display exists. •Medical monitoring and treatment of EVA crew is minimal. •Robotic EVA aids in use are primarily large arms with limited mobility and dexterity. Human capable rovers and mobile dexterous robots need additional attention. Most too reliant upon unique visual and handling aids. •Tools limited to manual force/torque reaction & zero-G transport/restraint. Limited environmental & mechanical analysis. No drills. Few true repairs. Delicate materials not easily handled.
logistics	•EVA overhead penalties are high in terms of mass, volume and time. 2600 lbs and 90 ft3 for suits, tools, carriers and consumables on STS-103 for HST. < 20% effective crew time. •Suit consumables are wastefully expended and require frequent replenishment or considerable time/power to recharge. No insitu resource utilization is possible. •No suit maintenance capability beyond limited resizing and consumables replacement. •Airlock designs waste gas/power and are not compatible with dust/biologic isolation.

EVA Health, Safety and Productivity Factors

Environmental Constraints

- Radiation (exposure time constraint and health risk)
- Gravity (extended exposure to reduced G weakens bones/muscles and limits sorties)
- Temperature (extreme hot and cold varies with altitude, seasons and day/night)
- Atmospheric pressure (impacts CO2 removal and thermal cooling systems)
- Lighting (limits work in unfamiliar areas w/o artificial lighting or depth perception shadowing)
- Dust and Wind (defeats pressure seals and obscures vision)
- Terrain (slopes/cliffs, obstacles, instability, hardness impede site access)
- Organic Contamination (2 way issue impedes productive time)

Sustained Health and Productivity

- Rate of EVA (4-5 days per week, no back to back days for any individual)
- Safe haven proximity (30 minute access, 7 hours outside, 10km walk, 1st stop is far point)
- Physical/mental endurance (overall and gloved hand - strength, abrasion, nerve impingement)
- Mechanical aids (pressurized/unpressurized transport, power/manual tools)
- Productive time (limited by assy/maint/ops overhead, exercise, sleep, meals, comm coverage)
- Mobility (limited by transport, worksite volume and suit mass/bearings/consumables)
- Five senses (degradation by enclosures can be compensated by info aids and sensors)

General Risk Mitigation

- Suit rechargability constraints (avoid nominally, safe return consumables cache)
- Mandatory duration of consumable margin (nominal and backup systems)
- Minimum comm and sensor/data definition (voice, email, suit, weather, navigation)
- IVA crew monitoring and buddy team pairing

EVA Architecture Goals/Guidelines

Overall

Develop as a safe, productive and affordable infrastructure for <u>anytime/anywhere</u> use

Near Term

- Address obsolescence and cost of current systems
- Enhance productivity and affordability of current STS/ISS programs
- Use ISS as an operational proving ground for new technology
- Foster people development and retention for long term efforts
- Maximize leverage by feeding requirements to non-EVA projects which have possible EVA benefits (info technology, robotics, nano technology)

Mid To Long Term

- Aim for solutions common to multiple locations (LEO, L1, Mars, Moon, Asteroids).
- Within ten years, be ready to support existing and future programs
- Pursue items common, interchangeable and critical to many systems
- End products should be safe, very reliable, lightweight, resource frugal, crew time efficient and comfortable for high frequency use in different environments
- Empower the suited crewmember to conduct tasks not possible or practical now

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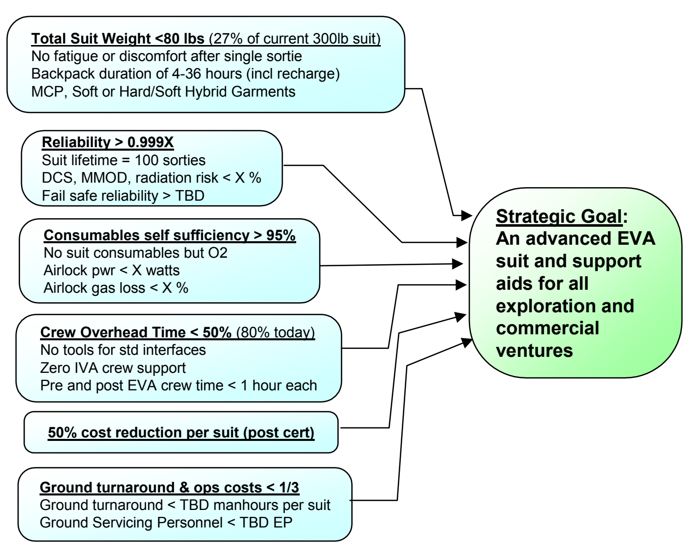
Overview of Advanced EVA Strategic Targets



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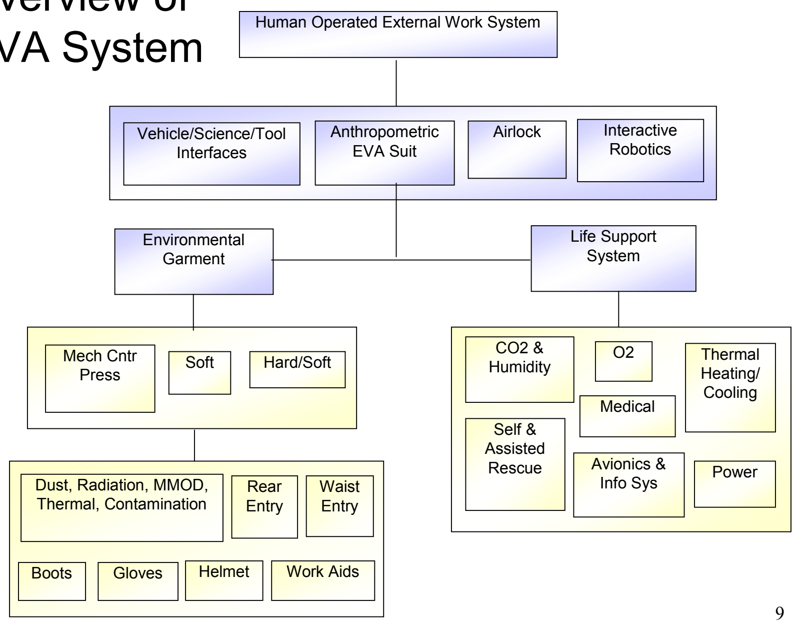
Overview of EVA System



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EVA Technology Challenges

1. CO2, humidity, trace gas removal
2. O2 storage and delivery
3. Low habitat and suit pressures
4. Thermal heating/cooling
5. Suit entry design
6. Anthropometric sizing
7. Backpack integration/maintenance
8. Self rescue integration
9. Gloves
10. MCP physiology and comfort
11. Dust protection
12. Radiation definition/protection
13. Contamination provisions
14. Low temperature tolerance
15. Low bulk multipressure thermal insulation
16. Strong, durable, light materials
17. Small high energy power supply
18. Wireless sensors/actuators
19. Airlock entry and exit
20. Airlock gas loss prevention
21. Decompression sickness (DCS) studies and monitoring
22. Hyperbaric treatment
23. Non intrusive medical sensors
24. Navigation and Communication
25. Multisensory info displays and controls
26. Automation
27. Freeflyer, manipulator and rover aids
28. Mechanical strength/dexterity aids
29. Ergonomic interfaces
30. Design/mobility/fit tools
31. Environmental test facilities
32. Vehicle interface standards
33. Field test experience and verification

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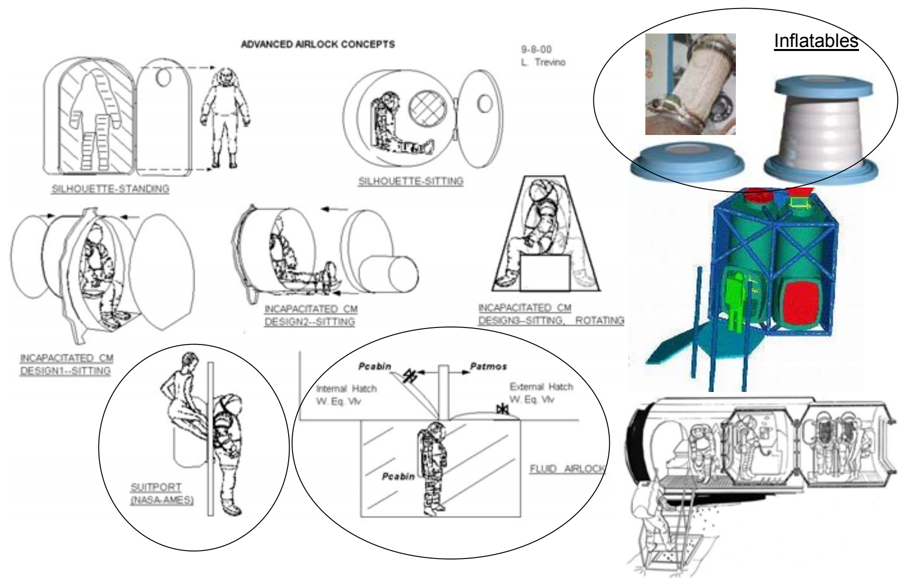
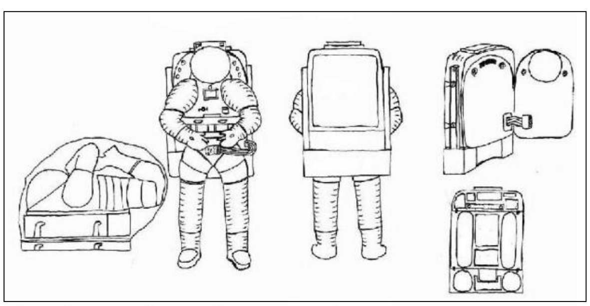
Airlock Concepts For Crew and Equipment

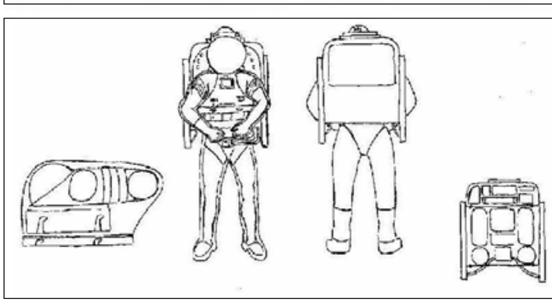


Advanced EMU Evolutionary Concept



2005

- Start with baseline current EMU and self rescue SAFER
- Replace waist entry torso with rear entry (2 sizes fit all)
- Replace metal bearings/disconnects with composites
- Eliminate chest mounted control module with flat panel display, voice actuation and crucial manual interfaces
- Consider 6 psi ops for STS/ISS prebreathe relief
- Relocate safety tether attach points for easy visibility
- Replace sublimator and H20 tanks with radiator cooling
- Repackage backpack after eliminating heavy structures
- Retain EMU TV, mini workstation and airlock umbilical
- Use LED lights to reduce pwr demand and battery ops
- Mass ~ 200 lbs (w/o SAFER self rescue)



2010

- Garment revised with MCP arms/legs and universal boots
- High pressure O2 and fan replaced with cryo and ejector
- CO2 scrubber lasts indefinitely without replace/regen
- 1-2 fuel cells replace all suit/accessory batteries
- Common gas supply for emergency life support and rescue
- GPS automatic rescue eliminates SAFER handcontroller and overboard return training
- Delete comm cap with suit integrated mics/speakers
- Automated electronic sun shades and visors
- New thermal insulation functional regardless of amb press
- Mass ~ 100 lbs (w/o SAFER self rescue)

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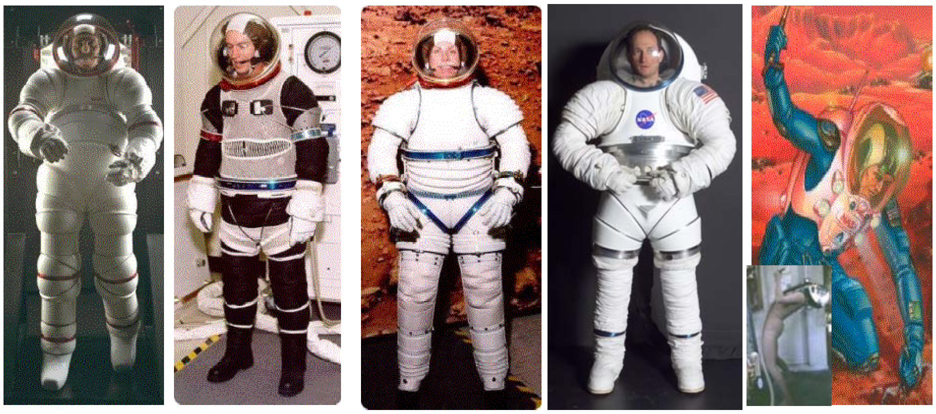
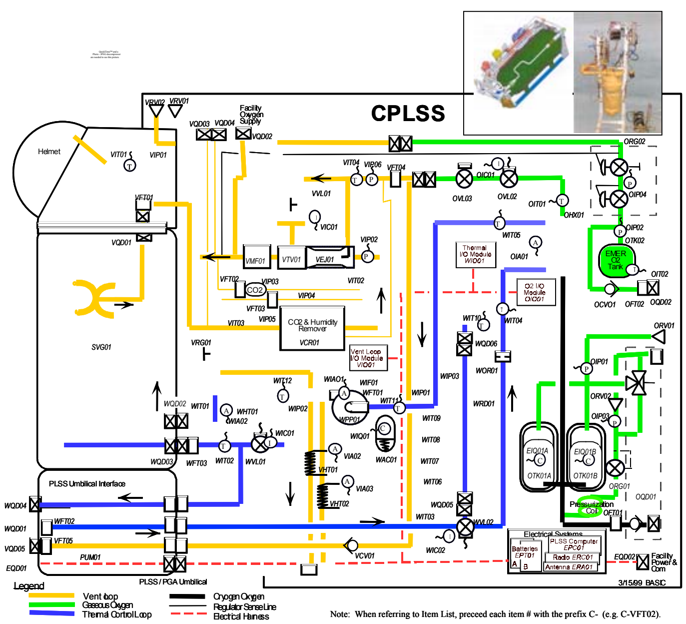
Advanced Space Suit Pressure Garment Candidates



ARC “AX5” | David Clark “D” | ILC “I” | JSC “H or Mark III” | Honeywell MCP

Note : Refer to Smithsonian EVA Garment History

ADVANCED SPACESUIT CRYO PLSS CONCEPT



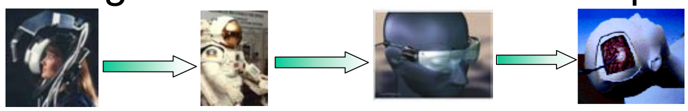
Note: When referring to Item List, preceed each item # with the prefix C- (e.g. C-VFT02).

Foam Mockup, 1997-8

Leading Tech Candidates

- Membrane, Swing Bed, Cryo or Laser CO2 Removal
- Cryogenic Oxygen
- Ejector Vent Flow
- Radiator Heat Rejection
- Auto Thermal Control
- Fuel Cell Power
- Wideband Radio

Intelligence Enhancement Concepts



4. **Data Display** - Interactive, hands free for system telemetry/functions, procedures and photo/TV images of environment and vehicle interfaces. Capability for crew and ground team updates of software format and content. Multiuse displays to be portable for suit or vehicle mounting. Helmet, arm or portable displays featuring miniature optics, low power, low profile and voice activation - Organic LED, Retinal, Visor HUD

- **Environment sensors** - miniature, low power, wireless, hand held or suit mounted for magnification, range, spectrometry, x-ray, UV, IR, radar, low light, geochemistry, biochemistry, electromagnetic fields, radiation, biological contamination, propellant/coolant contamination, ambient atmospheric sound)
- **Camera** - digital, still/video, small, low power/light, multiwave length, variable focus/range, pointing feedback
- **Life support sensors** - low mass, ultra-low volume, low power, wireless
- **Medical sensors** - Non-invasive, low power, wireless, 100% O2 compatible for blood N2, ECG, temp, fatigue
- **Software** for continuous autonomous system monitoring, trend analysis, diagnostics, malfunction response and feedback for EVA systems (airlock, suits, robotics, tools)
- **Digital radio** - Ultraminiature, low power, long range, multiuser for voice, video, data, commands - UWB
- **Navigation and crew tracking** - Autonomous terrain/spacecraft mapping, navigation and crew tracking integrated with crew and ground team displays. Data supplied by satellite, robotics or cameras attached to suited crew. Target recognition for artificial landmarks (e.g. colored/patterned flags, targets, radio beacons)
- **Voice command/control** between crew, suit, robotics and vehicle systems
- **Mobility sensing** fiber optic shape tape for suit design decisions and robotic interaction
- **Electronic Logbook** - Adaptive, collaborative for labeling, recording, cataloguing and retrieval of task data (material samples, photos, video, technical notes, etc)
- **Inventory management system** - autonomous and accessible by crew and ground teams - IR tags
- **Lighting** - small, low power, high intensity, suit mounted, portable - LED's

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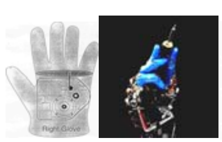
Mechanical Augmentation Concepts

Portable radiation shelters (artificial magnetic field or unpressurized "garage" with passive shielding)

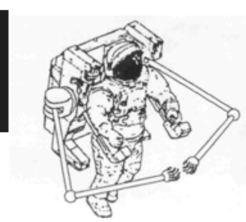
"Exoskeletons"

Hand Tools

Accordian Mobility



Power Assist Glove (Univ MD) and Mechanical End Effector Substitutes



MMU with Manipulators

Man in Can

Note : Lower B&W Images from Univ of Maryland, 1997

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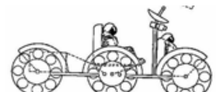
Robotic Aids For Planetary and 0-G EVA

Rovers (open, closed, small), Manipulators, Drills, Freeflyers

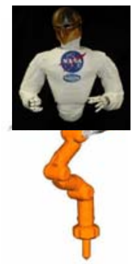


LOTRAN, Eagle Engr

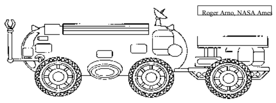
Sojourner

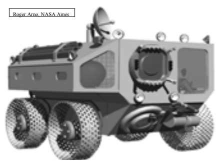
Nomad

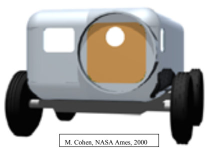
Skyworker, Carnegie Mellon



Robonaut





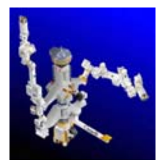


DANTE

ERA

AERcam

ISS RMS



ISS SPDM

RANGER, Univ MD

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Development Facilities

Field Test Site and Silo
Airlock Outfitting Concepts

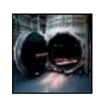
Suit Development Lab

Environmental Test Chambers

S/S Chamber

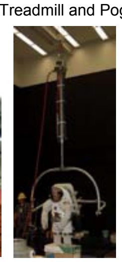
Z-Chamber

Chamber B



Chamber A

Treadmill and Pogo Weight Relief System



Glove Box

Liquid Air Portable
Life Support

Earth Analog Habitation and
Indoor Human/Robot Test Site

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2000 Field Tests – JSC and Flagstaff, NM

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Advanced EVA Technical Priorities

1. Integrated Concept Definition and Requirements (suit, airlock, robotics)
2. CO_2 system
3. Mass/Volume reduction and system definition (SSA and LSS)
4. O_2 system
5. Environmental Protection (thermal, puncture, radiation, dust)
6. Thermal Control System
7. Test Personnel and Facilities
8. Analysis Tools
9. Power supply system
10. Instrumentation and info technology (wireless, sensors, automation, controls/displays and crew/vehicle interfaces)

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Expected Benefits

• Wide range of distant destinations & applications
• Free up ground/crew time for non-EVA uses
• Minimized resupply mass/volume and consumables
• Lower production and utilization costs
• Productive, reliable and simpler performance of difficult tasks

Summary

• EVA is a cross cutting infrastructure which is fundamental to enabling current and future exploration and commercial endeavors
• New initiatives are being sought within NASA to allow viable and sustainable advanced technology development with the goal of creating a more capable and cost effective integrated EVA system within the next 10 years
• Opportunities to cooperate with external expertise are welcome

BACKUP

Why Humans?

While automated means are appropriate for selected applications, the combination of human and robotic capabilities provides leverage to enable otherwise difficult or impossible ventures.

Productivity - Use of the brain's creative cognitive abilities enables rapid on-scene decisions which overcome time delays and data bandwidth limits.

Reliability – Adaptive and proven capability for manual response to unforeseen, unique and non-repetitive activities

Cost/Mass – Less need to expend resources upon complex, redundant and fully automated designs

Terrestrial Benefits – Human space activities engage public interest and advance new opportunities

$$\textbf{Metrics} = \frac{\text{data}}{\text{mission}} \times \frac{\text{\# missions}}{\text{year}} \times \left(\frac{\text{automation + human costs}}{\text{mission}}\right) \times \text{risk \%}$$

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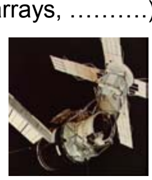
Past and Current In-Situ Tasks For Humans

- Apollo lunar geology prospecting and instrument deploy
- Skylab (solar array release, thermal shield install, science repairs)
- Mir (solar array assembly, docking system repairs, external science, commerce)
- Shuttle contingencies (Ku antenna stow)
- Satellite servicing (Solar Max, Westar/Palapa, Leasat, GRO, Intelsat, Eureca, Spartan, HST)
- ISS planned and unplanned assembly (mech, elec, fluid)
- ISS maintenance/repair (2A FGB antennas, 2A.2a Node antenna, 2A.2b SM TV target, 4A solar arrays, ……….)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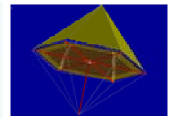
Future Tasks

In-Space Exploration

- Assembly and maintenance of large telescopes
- Asteroid exploration and exploitation
- ISS external maintenance and science
- STS/RLV contingencies and payload support

Planetary Exploration

- Assembly and maintenance of transit spacecraft
- Infrastructure setup & repair
(power generation/distribution, radiation shielding)
- Science equipment setup and repair
(surface sensors, drills, rovers)
- Access and study of challenging terrain
(outcrops, ravines, rock fields, subsurface)
- Rescue (crew and hardware)


Commercial Ventures

- Satellite servicing
- Assembly and maintenance of space based manufacturing, power generation, tether based launch services, tourism

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EVA Exploration Requirements (Draft, May 2001)

1.0 Introduction	10.0 Tools
2.0 Task Definitions and Operations Scenarios	11.0 Information Technology
3.0 Overall Resource Allocations and Needs	12.0 Human Factors
4.0 Strategic Groundrules, Constraints and Assumptions	13.0 Medical Constraints
5.0 External Environments	14.0 Safety/Hazard Controls
6.0 Vehicle and Science Interfaces	15.0 Standards
7.0 Robotic Interfaces	16.0Training, Development and Processing Facilities
8.0 Airlock	17.0 Hardware Verification
9.0 Suit/Umbilicals	

http://www.jsc.nasa.gov/xa/advanced.html

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Needed Enabling Information and Technology

Environmental Data

- UV and particle radiation levels at surface
- Season, daily and altitude variations of atmospheric composition, temp, press, dust, natural lighting and wind speed/direction
- Dust and wind impacts to convective/radiation heat transfer and solar flux
- Soil/dust chemical composition, reactivity, electrostatic charge, size, shape, mass
- Soil bearing strength, penetration resistance, cohesion, adhesion, abrasion
- Amount of trapped pressurized fluids/gases, volatile gases and toxic materials
- Terrain characteristics and maps (slopes, cliffs, caves, ravines, craters, obstacle size/distribution, surface instability, subsurface/rock hardness)
- Touch temperatures of surface and subsurface materials
- Short/long term effects from corrosion and abrasion of suit materials and coatings

Technology

- Portable life support, surface transport, airlocks, info/nav aids, robotics, facilities
- Radiation protection, insitu resources, compact power, sample curation

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Ground Test Experience

- Apollo/USGS experience, 1970's
- Comparative suit mobility tests (EMU, Mark III, AX-5), JSC, 1980's
- Comparative suit mobility tests (A7LB, EMU, Mark III), JSC, 1996
- Shirt sleeved geology exercises, Death Valley, 1997
- Lower torso mobility tests (Mark III), KC-135, 1997
- Mobility and geology exercises (Mark III), Flagstaff, 1998
- Remote site experience, Antarctica, 1998
- Mobility and robot aid tests (I-suit, Marsokod rover), Mojave Desert, 1999
- Mobility tests (D, I and H suits), JSC, 1999
- Reconnoiter of Devon Island as future test site, Canada, 1999
- Rover seating tests, KC-135, 2000
- Mobility, geology, drilling, power deploy demos (ATRV rover, H/I suits), JSC, 2000
- Mobility, geology, drilling, power deploy demos (ATRV rover, H/I suits), Flagstaff, 2000
- Remote site experience, Antarctica, 2000/1

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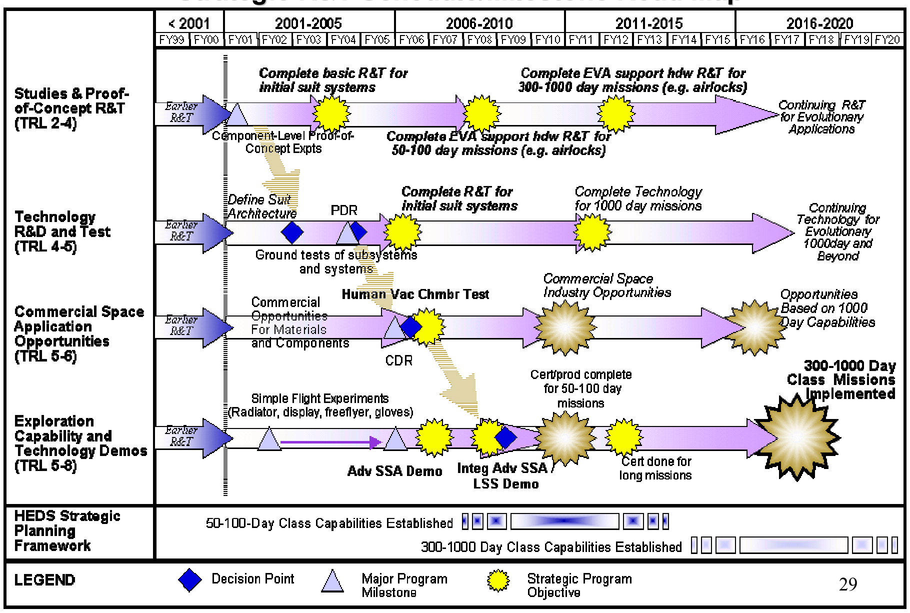
HEDS Technology/Commercialization Initiative
Advanced EVA Systems

Strategic R&T Schedule/Milestone Road Map



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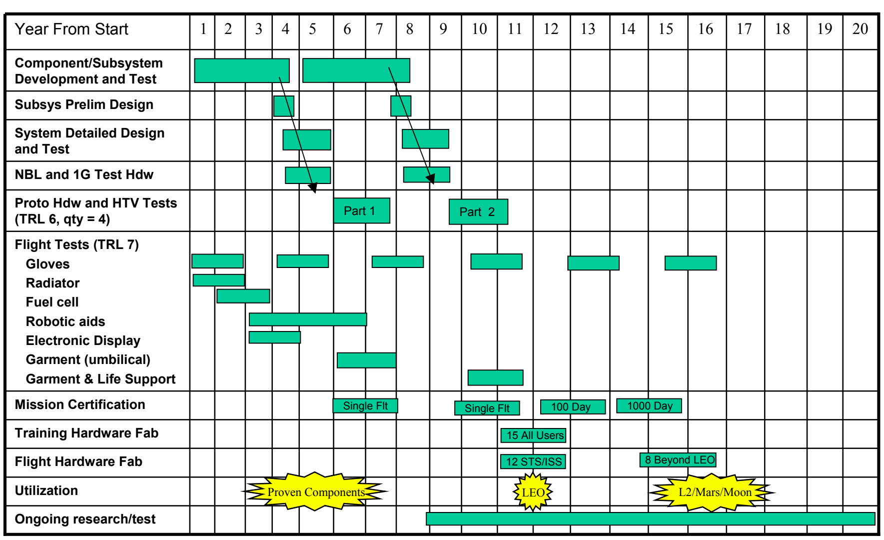
2 Phase Option For Advanced EVA Development



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Past and Future Commercial Applications

1. EVA is a proven valuable tool to enable commercial ventures
   - Satellite servicing
   - Assembly and maintenance of space based manufacturing, power generation, tether based launch services, tourism
2. Terrestrial users can apply EVA technologies (firefighter garments and breathing sources, underwater dive industry/tourism, submarine life support, medical sensors and isolation garments, etc)
3. EVA is a microcosm of large scale human rated projects. Commercial mass production or upscaling for terrestrial and space habitat/rover users is feasible to lower unit costs. Shared commonality and experience enhance reliability, maintainability and redundancy. Candidates include garment materials and LSS components.

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Technical Information References

JSC EVA Project Office	**http://www.jsc.nasa.gov/xa/advanced.html**
JSC Crew & Thermal Systems Div	**http://ctsd.jsc.nasa.gov/ESS/advanced.html**
Conferences	**Refer to XA website (ICES, STAIF, AIAA, IAF, LPI)**
Advanced EVA Forum	**Next event TBD**

Solicitation/Proposal Means

HEDS Technology and Commercialization Initiative	**http://research.hq.nasa.gov/code_m/code_m.cfm**
Office of Biological & Physical Research	**http://peer1.idi.usra.edu/**
	http://research.hq.nasa.gov/code_u/open.cfm
SBIR	**http://sbir.nasa.gov/**
Reusable Launch Vehicle	**http://nais.msfc.nasa.gov/cgibin/EPS/synopsis.cgi?acqid=83261**
NASA Institute for Advanced Concepts	http://ntpio.nasa.gov/niac/ & http://www.niac.usra.edu
National Space Biomedical Research Institute	**http://www.nsbri.org/**
Intelligent Systems Program	**http://ic-www.arc.nasa.gov/ic/nra/**
National Nanotechnology Initiative	**http://nano.gov/**
Competitive Procurements	**http://nais.msfc.nasa.gov**
University Space Grants and EPSCOR	**http://calspace.ucsd.edu/spacegrant/ or /epscor/**
Other	**Space Act Agreements, Unsolicited Proposals**

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